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Nanotechnology in the Military

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ABSTRACT

Nanotechnology is the study and manipulation of matter at incredibly small sizes. It is used across all scientific and engineering fields. Nanotechnology research and development has a great role to play in materials and systems for military use. It has been a boon with its many military applications, and research conducted for military purposes can have great benefits in civilian contexts as well. The potential military applications of this technology are vast, from creating lightweight and durable armor to developing medical solutions to rapidly heal injuries on the battlefield. This paper focuses on the use of nanotechnology in various military applications.

KEYWORDS: *nanotechnology, nanomaterials, military, army, defense, national security*

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INTRODUCTION

Technology has always been key to winning wars. Wars are often won by the force with the greatest technological advantage. For this reason, technology is a central focus of defense industry research. The military has always been at the forefront of technology. Technological advances have always been an effective way to give one army a winning edge over the other. Military innovation, even in peacetime, has become an extension of war itself. Military research, however, is more than just going to war; it also enables technological advances outside of the military. For example, military research has created drones, stealth aircraft, and an improved understanding of composite materials.

Nanotechnology signifies the research and development (R&D) of technology at the nanoscale. It is the study and manipulation of matter at incredibly small sizes. The application of nanotechnology, specifically in the area of warfare and defense, has paved the way for future research in the context of weaponization. Advancements in this area have led to the development of nano-weapons, small robotic machines, hyper-reactive explosives, and electromagnetic super-materials. Nanotechnology represents a significant opportunity for the military to enhance the way soldiers are equipped to fight. Some potential military applications of nanotechnology are already quite advanced, and will come into play much sooner than others. For example, many sensors have already been developed which take advantage of the unique properties of nanomaterials to become smaller and more sensitive, compared to conventional technology. Portable, efficient sensors will be highly valuable to military field operatives.

WHAT IS NANOTECHNOLOGY?

Technologies impact every aspect of our modern society. There are many ways in which our society and technology are interlinked. Nanotechnology has the potential to provide huge benefits, just like any useful technology.

The term “nano” means something small, tiny, and atomic in nature. The application of the term in science led to a field called nanotechnology. Nanotechnology refers to the characterization, fabrication and manipulation of structures, devices or

materials that have one or more dimensions that are smaller than 100 nanometers. It may be regarded as an area of science and engineering where phenomena that take place at the nano-scale (10-9m) are utilized in the design, production, and application of materials and systems. It is an emerging area of that integrates chemistry, biology, and materials science to create new properties that can be exploited to gain new market opportunities [1].

Nanotechnology deals with the characterization, fabrication, and manipulation of biological and nonbiological structures smaller than 100 nm. Dimensions between approximately 1 and 100 nanometers are known as the nanoscale. As indicated in Figure 1 [2], the nanoscale is so small that we cannot see it with a light microscope. It is the scale of atoms and molecules. Nanotechnology involves the creation and application of materials and devices at the level of molecules and atoms. It may be regarded as the science that is conducted, researched, investigated, and experimented at the nanoscale. Nanotechnology is a multi-disciplinary field that includes biology, chemistry, physics, material science, and engineering. It is the science of small things—at the atomic level or nanoscale level. The past three decades has witnessed an increased interest and funding in nanotechnology. This has led to rapid developments in all areas of science and engineering [3].

- Richard Feymann, the Nobel Prize-winning physicist, introduced the world to nanotechnology in 1959 and is regarded as the father of nanotechnology. Nanotechnology involves the manipulation of atoms and molecules at the nanoscale so that materials have new unique properties. Nanomaterials are expected to have at least one dimension (length, width, height) at the nanoscale of 1 – 100 nm. One nanometer is a billionth of a meter, too small to be seen with a conventional lab microscope. Nanomaterials include nanofilters, nanosensors, nano photocatalysts, and nanoparticles. Nanomaterials are known as nanoparticles when they have nanoscale length, width, and height. Figure 2 portrays a technique for the preparation of nanoparticles [4].

Today, nanotechnology is part of our daily lives. Nanotechnology will leave virtually no aspect of life untouched. Its usages include everything from safer food processing to more efficient drug-delivery systems to powerful computer chips. Three steps to achieving nanotechnology-produced goods are [5]:

1. Scientists must be able to manipulate individual atoms.
2. Next step is to develop nanoscopic machines, called assemblers, that can be programmed to manipulate atoms and molecules at will.
3. In order to create enough assemblers to build consumer goods, some nanomachines called replicators, will be programmed to build more assemblers.

Nanotechnology is trending among scientists and engineers. Here are some underlying trends one should look for [6]:

1. Stronger Materials: The next generation of graphene and carbon devices will lead to even lighter but stronger structures.
2. Scalability of Production: One big challenge is how to produce nanomaterials that make them affordable. Limited scalability often hinders application.
3. More Commercialization: In addition to transforming the automotive, aerospace, and sporting goods fields, nanotechnology is facilitating so many diverse improvements: thinner, affordable, and more durable.
4. Sustainability: One main goal of the National Nanotechnology Initiative, a US government program coordinating communication and collaboration for nanotechnology activities, is to find nanotechnology solutions to sustainability.
5. Nanomedicine: There will be a mindboggling impact of nanotechnology on medicine, where advances are being made in both diagnostics and treatment areas.

Applications of nanotechnology are found in a wide range of industries, including engineering, medicine, microelectronics, manufacturing, biology, chemistry, energy, and agriculture, and life sciences. Figure 3 shows some applications of nanotechnology [7]. Although nanotechnology has been successfully applied in various industries, its use in the oil and gas sector is still limited.

MILITARY NANOTECHNOLOGY

Nanotechnology is the conception, formation, design and application of valuable materials, instruments, and systems through the maneuvering of matter on minute scale. The use of nanotechnology in the area of warfare and defense has been rapid and expansive. Military applications of nanotechnology range from improved materials for soldiers' personal protection to sophisticated sensors capable of detecting chemical and biological threats. The US Department of Defense (DoD) nanotechnology program is grouped into seven program component areas, shown in Figure 4 [8].

Robotic drones are already operated by remote control. Advances in nanotechnology will allow both robotic systems and control systems to become smaller and more effective. It appears likely that most military technology will be dependent on nanomaterials. Some of the more potential applications in this area include [8,9]:

- Nano-machines to mimic human muscle action in an exoskeleton
- Stealth coatings
- Self-healing (self-repair) material
- Smart skin materials
- Adaptive camouflage
- Adaptive structures
- Increased surveillance for better protection
- Smaller cameras
- Cheap, small, and more effective weapons
- Exploration of the oceans
- Augmenting human performance
- Scratch resistant surfaces
- Stronger, thinner, and cheaper glass
- Coatings that do not degrade
- Lighter, faster aircraft which use less fuel
- Submarines and planes that can go undetected by radar
- Faster intensive medical help
- Nano-size umbrellas

APPLICATIONS OF MILITARY NANOTECHNOLOGY

Nanotechnology has numerous military applications. The most obvious are in materials science. Some other applications of nanotechnology include medicine, biological and chemical sensors, explosives, electronics for computing, power generation and storage, and structural materials for making vehicles, coatings, filters, and fabrics, and many of these applications have non-military uses as well. Some of these applications are shown in Figure 5 [10]. The main goals of military research into nanotechnology are to improve medical and casualty care for soldiers, and to produce lightweight, strong and multi-functional materials for use in clothing.

- *Military Clothing:* Military clothing gives protection against environment, camouflage, specific battlefield threats, flame, heat and flash, insects, chemical and the ergonomic considerations to maintain physical comfort properties. These qualities are possible only by integrating nanotechnology. Clothing worn in combat situations must be durable, crack resistant, sometimes waterproof, and must be able to operate in extreme weather conditions. For this reason, improved body armor is a major focus for military nanotechnology research. Nanomaterials like carbon nanotubes and diamond fibers have higher strength-to-weight ratios than steel, which allows for lighter and stronger armor. The Institute for Soldier Nanotechnologies (ISN) has provided an opportunity to focus funding and research activities purely on developing armor to increase soldier survival. Additional characteristics include energy-absorbing material protecting from blasts or ammunition shocks, engineered sensors to detect chemicals and toxins, as well as built in nano devices to identify personal medical issues. Fighting in extremes of hot and cold can severely restrict combat capability. This problem could be alleviated with nanowires and hydrogels which can keep soldiers cool in hot deserts and jungles as well as warm in frigid climates. Soldiers and vehicles will soon be equipped with micro antennas which can be inlaid into a soldier's uniform with nanomaterials inter-woven into the textile. Figure 6 show typical military uniforms [11].
- *Military Medicine:* It is important for a nation to ensure that the fighting force has the best possible medical equipment and techniques before, during, and after combat. In the field of military medicine, nanotechnology opens up new possibilities for treating injuries and diseases. Nanoparticles can be used to target drug delivery, speed up wound healing, or even create "smart" bandages that monitor the condition of a wound and release antibiotics as needed. Military medicine has been evolving over the course of millennia. The more advanced a military's wartime medical capabilities, the more likely the combatants are to survive, recover faster and more completely, and return to duty sooner. Medical improvements during the critical initial period of injury increase the chances of survival and minimize the long-term impact of injury. Improved medical technologies during rehabilitation can shorten recovery time and improve the quality of life for service members who either return to active duty or return to their civilian lives. One technology proving multiple applications to medical care during and after combat is nanotechnology. Several advantages to having access to materials on nano scale include a drastic increase in surface area to volume ratio, the ability to directly target specific tissues, and the ability to create new and novel shapes of particles. These advantages are critical in nanotechnology's medical possibilities. One of

the most anticipated uses of nanomedicine is for the development of new classes of pharmaceuticals and drug delivery systems, especially for targeted therapies. Figure 7 illustrated the application of nanotechnology in military medicine [12].

- *Military Weapons:* Research into military nanotechnological weapons includes production of defensive military apparatus, with objectives of enhancing existing designs of lightweight, flexible, and durable materials. These innovative designs are equipped with features to also enhance offensive strategy through sensing devices and manipulation of electromechanical properties.
- *Communications:* Traditional communication systems, such as wired and wireless systems, have limitations when it comes to military and defense applications. They are not suitable for remote locations, and they are vulnerable to interception. VSAT (Very Small Aperture Terminal) technology is the best option for military and defense applications. It offers secure, reliable, and high-speed connectivity to remote locations. Nanotechnology designed for advanced communication is expected to equip soldiers and vehicles with micro antenna rays. It facilitates easier defense related communications due to lower energy consumption, light weight, efficiency of power, as well as smaller and cheaper to manufacture.
- *Power Generation:* The electrical power sources can be integrated into the textile which remained washable. For example, nano-enabled photovoltaic, thermoelectric, and piezoelectric devices are on the cusp of being able to harvest electricity from solar energy, waste body heat, and kinetic motion from a soldier's movement. In most cases, these power sources could be embedded directly inside the uniform fabric. The common option for powering portable electronics for both military and non-military use are lithium-ion batteries due to their high energy density, long lifespan, and because they are rechargeable. Battery designers are looking at how to use graphene. The 21st century soldier is weighed down with batteries for electric laptop computers, handheld computers, night-vision goggles, and optoelectronic rifle sights. That load could soon be reduced using nanoparticles. Nanotechnology offers many ways to move electricity to the battlefield.

MILITARY NANOTECHNOLOGY AROUND THE WORLD

Nanotechnology, a field that deals with the manipulation of matter at the atomic and molecular level, is revolutionizing the military around the world, as typically shown in Figure 8 [13]. Industries and governments across the world are investing heavily in nanotechnology. Over the past two decades, numerous countries have funded military applications of nanotechnology including United States, China, United Kingdom, and Russia. Between 2001 and 2004, approximately 60 countries globally implemented national nanotechnology programs. The North Atlantic Treaty Organization (NATO) is intensively exploring the potential of these miniature technologies to strengthen the defense capabilities of its member states. Nanotechnology in the context of NATO represents not only a technological revolution but also a strategic imperative. We consider the application of military nanotechnology in the following nations [14,15]:

- *United States*: The US government has been considered a national leader of research and development in the area of nanotechnology. However, US is now rivalled by international competition as appreciation of nanotechnology's eminence increases. In 2000, the United States government developed a National Nanotechnology Initiative (NNI) to focus funding towards the development of nano-science and nanotechnology, with a heavy focus on utilizing the potential of nano-weapons and coordinating application of nanotechnology among all military factions including Air Force, Army and Navy. The NNI is aimed at coordinating Federal nanotechnology research and development in the United States. Since then, the overall DoD investments (hundreds of millions of dollars) in nanotechnology each year has remained high. DoD plans to continue with this priority throughout the 21st century. The United States is the only country that has chosen to dedicate specific investments in nanotechnology-based programs for defense purposes. For the US, maintaining technological superiority constitutes a strategic advantage. DOD lists nanotech as one of 'its major strategic research programs, and spends more money on nanotechnology research than many other areas. Some examples of programs sponsored by the DOD include MIT's Institute for Soldier Nanotechnologies and the Defense University Research Initiative on NanoTechnology, which aims to support and promote nanotechnology research relevant to national defense at US universities.

- *China*: China, like the US, is focusing much of its R&D investment on military applications. In nanomaterials, China secures second place behind the United States in the amount of research publications they have released. China now produces more research papers on nanotechnology than any other nation. Conjecture stands over the purpose of China's quick development to rival the US, with 1/5 of their government budget spent on research (US$337million). In 2018, The scientific nanotechnology team at Tsinghua University, Beijing hinted at aerospace, and armor boosting applications, showing promise for defense related nano-weapons. The Chinese Academy of Science has stated the need to focus on closing the gap between "basic research and application," in order for China to advance its global competitiveness in nanotechnology.
- *Europe:* In its communication entitled "Toward a European Strategy for Nanotechnology," the European Commission estimates that the future market for products issued from nanotechnology could rise to hundreds of billions of Euros by 2010 and to one trillion thereafter. It is only to a lesser extent that ethical, societal, and health concerns about nanotechnology have been discussed. Although simple forms of nanotechnology are used in a few consumer products—like some new semiconductors, sunscreens, and stain-resistant trousers—it is not clear that such products are worth billions of taxpayer dollars. Nanotechnology will inevitably lead to disruptive technologies. If such technologies could lead to the development of a new generation of weapon systems and combatants, they could also give rise to the growth of disturbing factors affecting the global military balance. It took times before the EU realizes the necessity to develop a genuine strategy in the field.
- *Russia:* Emerging technologies are often perceived as carrying the potential to revolutionize governmental structures, economies, militaries, and entire societies. Russian leadership shares that belief. Russia has invested in nanotechnology for military purposes in a number of ways. In April 2007, then Russian president Vladimir Putin extolled nanotechnology research as the key to establishing Russia's competitive advantage in the hightech world economy and the next round of the arms race. The Russian parliament approved a $7 billion investment in nanotechnology over five years. In 2018, Vladimir Putin's decree established ERA Technopolis, a military research and development (R&D) center that focuses on nanotechnology, AI, robotics, and other technologies.
- *India:* Considering the underlying salience of nanotechnology, India has been putting in a consistent effort in the field. The potential of nanotechnology in India was realized by 2001 when the government of India set up NSTI (Nanoscience and Technology Initiative). Since then, India has come a long way. It is carrying out extensive work in nanotechnology to enhance its application in the defense sector. DRDO has also set up a nano research and production facility in various parts of India. A Bengaluru-based Log-9 Materials startup is also collaborating with the defense industry to help it build multiple products and applications while conserving energy. However, the progress made by the country is not enough, and the process needs to be accelerated.
- *Israel:* This is the first country to publicly state they are planning to use nanotechnology in weapons. It seems to be stretching the point somewhat to suggest that no one has previously thought of sending nanotechnology to war. Several Israeli Universities such as Haifa's Technion, Jerusalem's Hebrew University and Tel Aviv University are exploring nanotechnology. Israel Aerospace Industries-Elta is teaming up with MassChallenge to develop nanotechnology set to transform both the civilian and military worlds.

BENEFITS

Nanotechnology has many benefits in the military. It offers numerous advantages, such as lighter and stronger materials, improved sensors, and targeted drug delivery systems. It can help wounds heal faster and reduce the risk of infection. For example, nanomaterials like silver and chitosan can be used to treat wounds. Artificial red blood cells and platelets can help reduce blood loss in traumatic injuries. Other benefits of military nanotechnology include the following [16]:

- *Automation:* As nanotechnology allows the further development of the "battlefield network," there will be a tendency to delegate more and more decisions to semi-autonomous systems which respond automatically to developing situations.
- *Lighter and Faster Vehicles*: Nanomaterial composites can provide added strength without extra weight. This can boost protection, increase speeds, and lower fuel consumption of aircraft, tanks, and ships. Stealth ships and aircraft are

being improved with the use of nanomaterials which can help "hide" military hardware.

- *Improved Armor:* Current equipment for bulletproof and blast-proof wearable protection is reaching the limit of what a soldier can carry. Further studies have shown that nanoadditives can be used in the polymers that make up modern dressings to provide antibacterial benefits. Armor has to prevent the energy from those projectiles from being transferred to the wearer. Body armor may stop a bullet from piercing the skin, but the energy transferred to the body from the impact may still kill the wearer.
- *Medical Care:* Nanotechnology is an emerging technology that has the potential to revolutionize military medical care. Nanotechnology can help deliver drugs and other medicines quickly and accurately. It can help monitor a soldier's health, such as their heart rate and blood pressure, using non-invasive technologies. It can also help with advanced medical monitoring and diagnostics.
- *Wound Treatment:* The threat of injury and even death hangs over the head of most active men and women in the armed forces. The treatment for some injuries can be life-threatening as well. Wound treatment in long-term care settings can be quite different than treatment on the battlefield. Nanomaterials of copper and silver have been proven to have antimicrobial effects which when applied to bandages can help to keep wounds free of infection. Nanotechnology also offers the promise of creating more efficacious vaccines and anti-infectives, which could be deployed easily to combat areas and remote locations. Figure 9 shows a wounded soldier [11].
- *Next Generation Drones:* Nanotechnology is finding ways to make ever smaller electronics which could be used to build miniature drones. It is possible that a large-scale fleet of tiny (and therefore hard to shoot down) drones could provide a destructive force if enough drones were applied to a specific high value target.
- *Soldier Protection*: Nanotechnology for the soldier is directly related to new functionalities in his suit, helmet or other portable equipment. The future war-fighter is equipped with powerful tools to cause drastic damage or to neutralize the opponents. He is in a smart uniform and smart helmet, which has sensors to protect him from ballistic elements. He identifies objects or enemies through RFID tags and a body area networks, consisting of a number of wireless products communicating with each other. The war-fighter has the ability to monitor his position, his physical and mental condition, and status of equipment.

CHALLENGES

While there are many benefits to military nanotechnology research, there are also several challenges which should be handled with great care as the technology progresses. It is vital not to overlook the role of the military in the development and dissemination of potentially harmful nanotechnology applications. Other challenges of military nanotechnology include the following [13,14]:

- *Regulation:* International regulations are non-existent for issues of nanotechnology and its military applications. There will be an enormous challenge to regulate the use of nanobots, miniature communications systems, etc. Some of the medical applications of nanotechnology, developed to improve solders' endurance and performance, would also need careful regulation for general medical applications. Ambiguity and a lack of transparency in research increases difficulty of regulation in this area. Producing legislation to keep-up with the rapid development of products and new materials in the scientific spheres, would pose as a hindrance to constructing working and relevant regulation.
- *Security:* Nanotechnology poses grave risks for international security and future military balances. Widespread availability of the nanotechnology-based devices would inevitably lead to their use for criminal activity and terrorist attacks. Although nanotechnology and its use in warfare promise economic growth, the promise comes with the increased threat to international security and peacekeeping. Such developments will have impact on geo-politics, ethics, and the environment.
- *Safety:* It is important that consumers and workers are ensured proper protection and safety when nanotechnology is used in the military. The introduction of nanotechnology into everyday carries the possibility of unknown consequences for the environment and safety. Convergences between nanotechnologies and biotechnologies should lead to new therapeutic agents of greater specificity and safety.
- *Environment:* While there are several positive environmental effects of nanotechnology, there are certain negative impacts as well which need to be addressed, such as increased toxicological pollution of the environment due to the uncertain shape, size, and chemical compositions of some of the nanotechnology products or nanomaterials.

The release of toxic nano-substances can cause environmental harm. Associated risks may involve military personnel inhaling nanoparticles added to fuel, possible absorption of nanoparticles from sensors into the skin, water, air or soil, dispersion of particles from blasts through the environment, alongside disposal of nano-tech batteries potentially affecting ecosystems. There can be some risks involved with engineered nanomaterials, which can also negatively impact the environment. For example, military activities can result in explosions; blasts by high-tech weaponry can release toxic nanoparticles.

- *Socio-ethical Concerns:* When discussing military applications of nanotechnology, it is equally important to discuss the social, environmental, and ethical concerns as well. It is unknown the full extent of consequences that may arise in social and ethical areas. The main ethical uncertainties entail the degree to which modern nanotechnology will threaten privacy, global equity, and fairness. An overarching social and humanitarian issue, branches from the creative intention of these developments. "The power to kill" highlights the unethical purpose and function of destruction these nanotechnological weapons supply to the user. The application of nanotechnology in certain areas of defense may in the future be deemed unethical or may simply upset the balance of power by creating a super-weapon or by rendering an opponent's weapons impotent.
- *Human Rights Concerns:* These concerns related to nanotechnology include uneven access to the benefits of technology, unfair distribution of the profits associated with technology, negative social and anthropological impact of the technology, privacy and informed consent.
- *Secrecy:* The secrecy behind military research and nanotechnology will make enforcing legislation impossible. It is impossible to determine if a nation is non-compliant if one is unable to determine the entire scope of research, development, or manufacturing. It is therefore difficult to know exactly where the technology is heading or what powers the weapons of the future will possess.
- *Autonomous Systems*: The integration of artificial intelligence and autonomous systems (such as drones and unmanned ground vehicles) into military defense has the potential to revolutionize warfare. Global tensions continue to rise as several nations invest heavily is the integration of autonomous weapons and nanotechnology into their defense strategies. Autonomous weapons are becoming increasingly prevalent in military operations around the world. For example. US and China have been investing heavily in autonomous weapons. The use of nanotechnologies in autonomous weapon systems should be strictly regulated by international agreements. It is crucial to ensure that the decision to use force always remains under direct human control, with clear accountability protocols. Figure 10 shows some autonomous systems [17].
- *Surveillance:* A robust legal and ethical framework is needed to balance the potential of nanotechnology for surveillance and intelligence gathering with the right to privacy. This framework should include clear rules for the use of nanotechnologies in security and intelligence, with an emphasis on protecting civil rights.
- *Asymmetric Warfare:* Military and security forces should develop comprehensive strategies and countermeasures for the potential misuse of nanotechnology in asymmetric conflicts. This includes the development of detection systems, protective measures, and tactics to counter nanotechnology-based threats.

CONCLUSION

Technology has always played a crucial role in military defense, and its importance has only increased in today's modern world. Nanotechnology is the understanding and control of matter at the nanoscale (roughly 1-100 nm), where unique phenomena enable novel applications. It is generally accepted that advances in nanotechnology will drive the next paradigm shift in science and technology. As with most new, emerging technologies, military applications of nanotechnology are likely to be the first to be realized. It appears likely that most military technology will be dependent on nanomaterials.

Currently, nanotechnology is evolving from the basic stage of its development into the applied research stage of technology maturity. It is highly promising prerequisite for military applications. It has not yet acquired the status of a sufficiently mature technology to allow analysts to foresee what could be its precise impact on political-military affairs in the coming decades. More information about nanotechnology and nanomaterials in the defense industry can be found in the books in [18-27] and the following related journals/magazines:

- Nanotechnology
- Nanoscale.
- Nano: The Magazine for Small Science

- Micro and Nano Technologies
- Nanotechnology News
- Nature Nanotechnology
- Current Research in Nanotechnology
- American Journal of Nanotechnology & Nanomedicine
- Nanomedicine: Nanotechnology, Biology and Medicine
- Journal of Nanotechnology
- Journal of Nanoparticle Research
- Journal of Bioelectronics and Nanotechnology
- Journal of Nanoscience and Nanotechnology,
- Journal of Micro and Nano-Manufacturing
- Journal of Nanoengineering and Nanomanufacturing
- Nanotechnology and Precision Engineering

REFERENCES

[1] M. N. O. Sadiku, M. Tembely, and S.M. Musa, "Nanotechnology: An introduction," *International Journal of Software and Hardware Research in Engineering,* vol. 4, no. 5, May. 2016, pp. 40-44.

[2] "Nanotechnology white paper," https://www.epa.gov/sites/default/files/201501/documents/nanotechnology_whitepaper.pdf

[3] M. N. O. Sadiku, Y. P. Akhare, A. Ajayi-Majebi, and S. M. Musa, "Nanomaterials: A primer," *International Journal of Advances in Scientific Research and Engineering,* vol. 7, no. 3, March 2020, pp. 1-6.

[4] U. A. Ali et al., "A state-of-the-art review of the application of nanotechnology in the oil and gas industry with a focus on drilling engineering," *Journal of Petroleum Science and Engineering,* vol. 191, August 2020.

[5] K.R. Saravana and R. Vijayalakshmi, "Nanotechnology in dentistry," *Indian Journal of Dental Research*, November 2005.

[6] N. S. Giges, "Top 5 trends in nanotechnology," March 2013, https://www.asme.org/topics-resources/content/top-5-trends-in-nanotechnology

[7] D. E. Effiong et al., "Nanotechnology in cosmetics: Basics, current trends and safety concerns—A review," *Advances in Nanoparticles*, vol. 9, 2020, pp. 1-22.

[8] S. Sengupta, "Nanotechnology and the military," November 2021, https://sustainable-nano.com/2021/11/11/nanotechnology-and-the-military/

[9] W. Soutter, "Nanotechnology in the military," June 2012, https://www.azonano.com/article.aspx?ArticleID=3028

[10] M. S. Abed and Z. A. Jawad, " Nanotechnology for defence applications," in N. M. Mubarak, S. Gopi, and P. Balakrishnan (eds), *Nanotechnology for Electronic Applications. Materials Horizons: From Nature to Nanomaterials*. Singapore: Springer, 2022.

[11] S. Hilton, "Nanotechnology and tomorrow's infantryman," April 2023, https://blog.polymernanocentrum.cz/nanotechnology-and-tomorrows-infantryman/

[12] "Applications of nanotechnology in military medicine: From the battlefield to the hospital and beyond," https://hdiac.org/articles/applications-of-nanotechnology-in-military-medicine-from-the-battlefield-to-the-hospital-and-beyond/#:~:text=Each%20category%20has%20direct%20applications,hemorrhage%20control%2C%20wound%20management%2C%20tissue

[13] "Another potential aspect of the military revolution: Nanotechnology as a key element of NATO's future," September 2024, https://www.czdefence.com/article/another-potential-aspect-of-the-military-revolution-nanotechnology-as-a-key-element-of-natos-future#:~:text=Nanotechnology%20allows%20for%20the%20development,of%20complex%20early%20warning%20systems.

[14] "Nanotechnology in warfare," *Wikipedia*, the free encyclopedia, https://en.wikipedia.org/wiki/Nanotechnology_in_warfare

[15] A. De Neve, "Military uses of nanotechnology and converging technologies: Trends and future impacts," http://www.irsd.be/website/images/livres/focus paper/FP08.pdf

[16] "Nanotechnology and the military: How tiny materials can win wars," https://blog.nanochemigroup.cz/nanotechnology-and-the-military-how-tiny-materials-can-win-wars/

[17] S. Alsabi, "'The rise of autonomous weapons and nanotechnology in military defense: A

global perspective' by AI," February 2023, https://www.linkedin.com/pulse/rise-autonomous-weapons-nanotechnology-military-defense-sultan-alsabi

[18] S. Tomar, *Nanotechnology: The Emerging Field for Future Military Applications.* Institute for Defence Studies & Analyses, 2015.

[19] D. Ratner and M. A. Ratner, *Nanotechnology and Homeland Security: New Weapons for New Wars*. Prentice Hall/PTR, 2004.

[20] M. N. O. Sadiku, S. M. Musa, T. J. Ashaolu, and J. O. Sadiku, *Applications of Nanotechnology.* Gotham Books, 2023.

[21] J. Altmann, *Military Nanotechnology: Potential Applications and Preventive Arms Control (Contemporary Security Studies)*. Routledge, 2005.

[22] M. A, Medina et al., *Nanotechnology in the Space and Military Industries: A review of trends. (Nanotechnology trends).* Independently Published, 2020.

[23] R. K. Sharma, *Military uses of nanotechnology.* Sumit Enterprises, 2014.

[24] N. Kumar and A. Dixit, *Nanotechnology for Defence Applications.* Springer, 2019.

[25] M. Sharon et al., *Nanotechnology in the Defense Industry: Advances, Innovation, and Practical Applications (Advances in Nanotechnollogy & Applications).* Wiley-Scrivener, 2019.

[26] L. A. Del Monte, *Nanoweapons: A Growing Threat to Humanity.* Potomac Books, 2017.

[27] M. Kosal, *Nanotechnology for Chemical and Biological Defense.* New York: Springer, 2009.

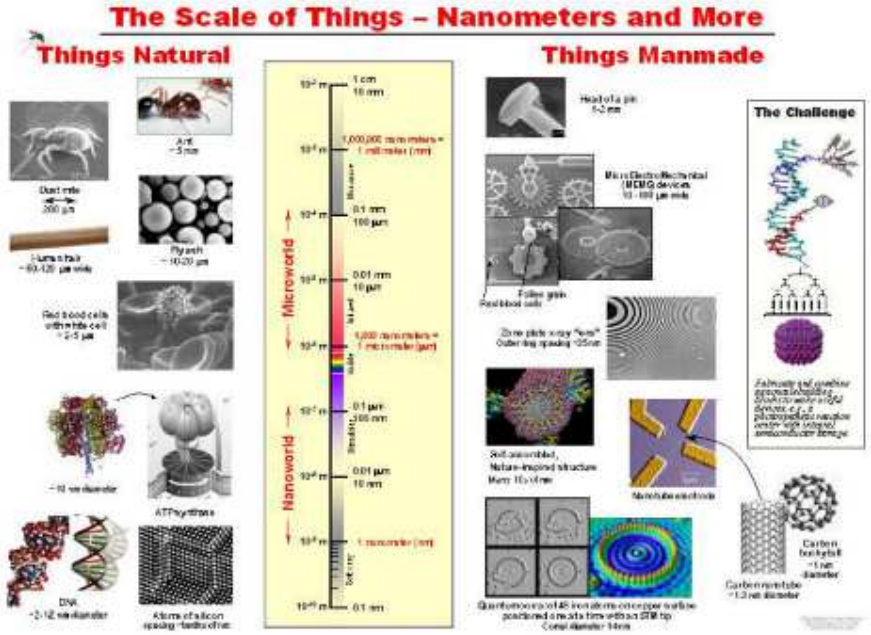

Figure 1 Indicating the relative scale of nanosized objects [2].

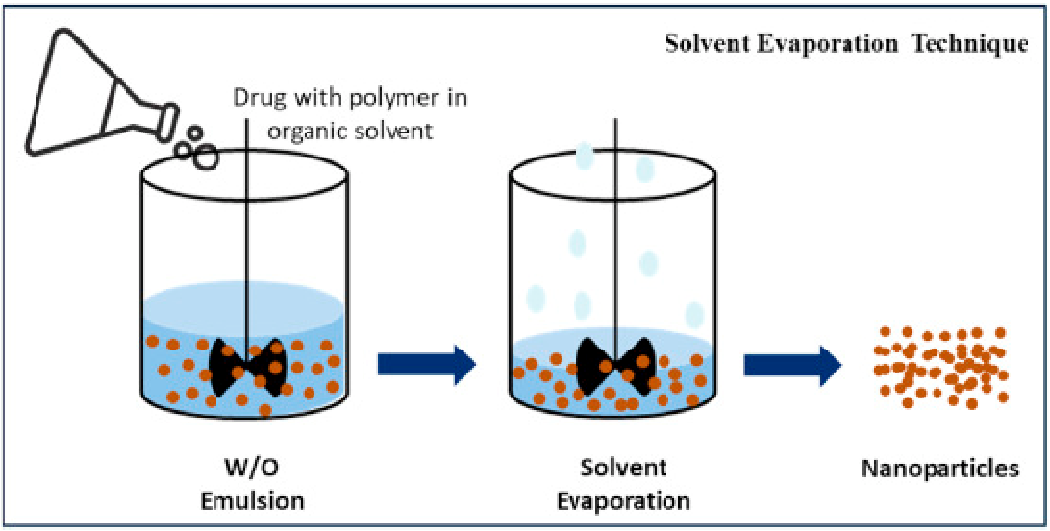

Figure 2 A technique for the preparation of nanoparticles [4].

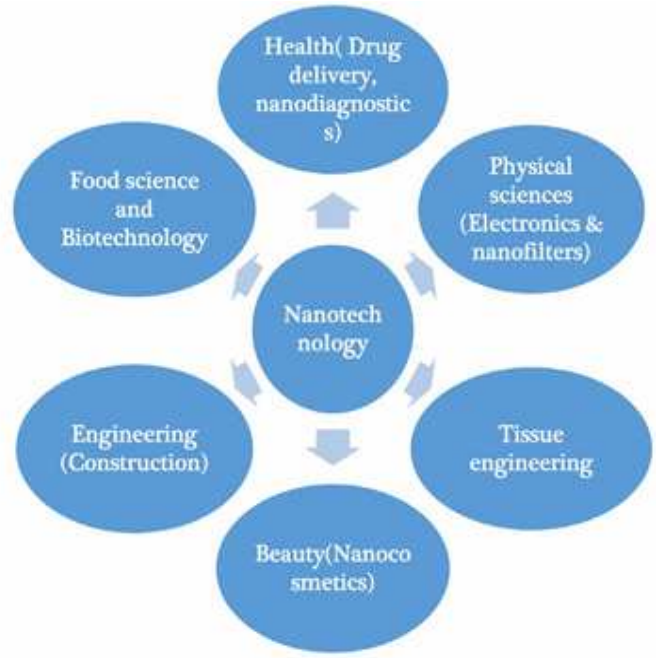

Figure 3 Some applications of nanotechnology [7].

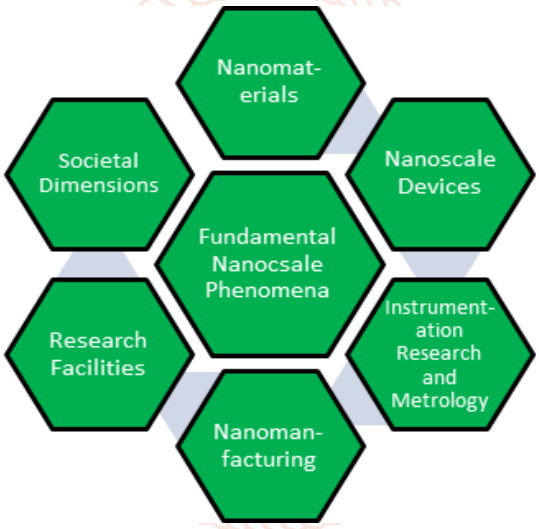

Figure 4 DoD nanotechnology program component areas [8].

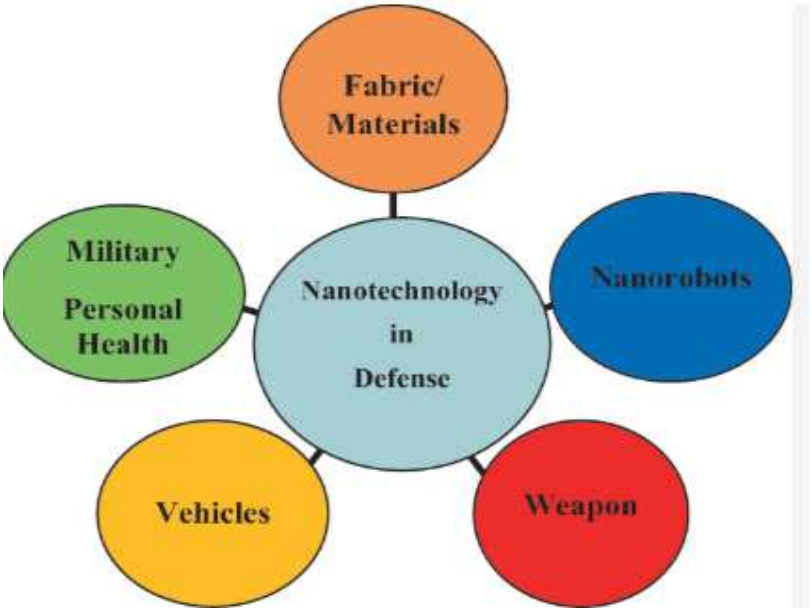

Figure 5 Some applications of nanotechnology in defense [11].

Figure 6 Typical military uniforms [11].

Figure 7 Application of nanotechnology in military medicine [12].

Figure 8 Nanotechnology revolutionizes the world of military [13].

Figure 9 A wounded soldier [11].

Figure 10 Some autonomous systems [17].